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(54) Discharge lamp systems.

(57) A method of extending discharge lamp life includes slowing electrode deterioration by powering the discharge lamp so that a lamp arc current having a reduced crest factor results, either by retrofitting an existing discharge lamp system with a waveform conditioning module, by powering the discharge lamp with a ballast producing a squarewave-type waveform, or by slowing deterioration of an emissive coating on a discharge lamp electrode by such means as preheating the electrode prior to use in order to bond the emissive coating on the electrode. A discharge lamp system includes a discharge lamp and components operatively coupled to the discharge lamp for supplying a lamp arc current to the discharge lamp that has a reduced crest factor and controlled lamp watt loading, such as a ballast configured to supply a lamp arc current with a waveform that is substantially a squarewave or an existing ballast retrofitted with waveform conditioning circuitry that causes the lamp arc current to have a reduced crest factor. A module is provided for retrofit purposes in order to tune an existing ballast and discharge lamp so that the crest factor is reduced.

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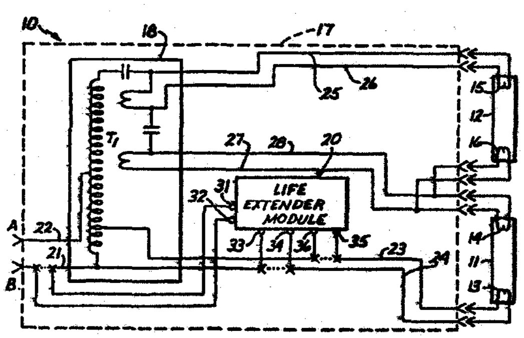


FIG. 1

DISCHARGE LAMP SYSTEMS

This invention relates generally to discharge lamps, and more particularly to a module, circuitry, and methodology for extending discharge lamp life.

A discharge lamp uses the technique of discharging electric current through mercury vapor and other gases to produce visible and ultraviolet radiation. As that happens in the case of fluorescent lamps, the ultraviolet radiation impinges upon a fluorescent coating on the lamp, causing the fluorescent coating to emit visible light that we can use for illumination purposes with notable efficiency. Thus, discharge lamps have come into widespread use so that the details of their construction and use demand attention.

Consider a fluorescent lamp for example. It includes a glass tube that the manufacturer coats with a fluorescent material, fills with mercury vapor, and supplies with an electrode at each end. We install the fluorescent lamp by plugging it into a lamp fixture designed to support the glass tube and supply electric current to the electrodes, the combination of the fluorescent lamp and lamp fixture sometimes being called a discharge lamp system.

The lamp fixture includes an electrical component called a ballast. The ballast transforms an external source of alternating current (such as 110-volt commercial or household current) to the voltage level necessary to operate the fluorescent lamp (i.e., high starting voltages, current-limited lower operating voltages, and any heater voltages required).

Two-terminal electrodes are used in what are called rapid-start type and pre-heat type discharge lamps (each electrode including a heater filament) and one-terminal electrodes are used in what are called instant-start discharge lamps (the electrodes being heated by the current flowing between them). Regardless of the type, we activate the ballast when we turn on the discharge lamp system and that causes an electric potential or voltage to be impressed across the lamp. An electric current (i.e., the lamp arc current) results that arcs between the electrodes, the electrons bombarding the mercury vapor thereby producing the ultraviolet radiation.

More specifically, the ballast impresses an alternating voltage across the electrodes so that each electrode acts as a cathode during one half-cycle and as an anode during the other half-cycle. Thus, the lamp arc current alternates in direction as it flows between the two electrodes. But the electrical characteristics of the ballast and fluorescent lamps are such that a highly distorted lamp arc current waveform results.

The ballast and fluorescent lamps are usually matched so that the fluorescent lamps operate at a prescribed efficiency and operational life expectancy, resulting in a highly distorted lamp arc current waveform that maintains lamp ignition and prescribed lamp brightness as well as having a direct effect on lamp lumen life and lamp mortality. The waveform may, for example, increase somewhat slowly to a peak and then rapidly decay to zero so that the ratio of the peak value to the RMS value (i.e., the lamp arc current crest factor) is about 1.7.

But the action of the lamp arc current slowly deteriorates the electrodes by depletion of the barium or other emissive electrode coating employed. We sometimes say that it causes the emissive coating to burn off, and such deterioration is affected by the lamp arc current crest factor.

In that regard, the electrodes are typically impregnated with rare earth oxides and other emissive elements that have an abundance of free electrons and low work functions. When the lamp is first installed and turned on, the electrodes heat up to operating temperature and that heats the emissive coating and causes more electrodes to be emitted to facilitate the Townsend avalanche and also bond the emissive material in place which typically occurs within one hundred hours of lamp operation. However, until that process is completed, the emissive coating is even more vulnerable to the action of the lamp arc current. In other words, it can blow off or burn off all the more rapidly and deteriorate lumen and lamp life.

After the electrodes have deteriorated sufficiently and the bare tungsten electrode is exposed, the fluorescent lamp is no longer useable and must be replaced. This can result in costly maintenance in large commercial installations and it is aggravated by the less frequent but regular failure of aging ballasts. Some users even replace all lamps and ballasts periodically rather than wait for the lamps and ballasts to fail. Thus, lamp maintenance can be very expensive and time consuming so that we need some way of extending discharge lamp life.

This invention extends discharge lamp life and lamp lumen life by slowing electrode deterioration. That is done according to one aspect of the invention by producing a reduced crest factor that is less than that of existing systems (i.e., less than about 1.7), either with a waveform conditioning module that is retrofitted to an existing ballast or with a ballast that produces a squarewave-type waveform, or electrode deterioration is slowed according to another aspect of the invention by slowing deterioration of the emissive coating on

the electrode, such as by preheating the electrode before, during, or after fabrication so that the emissive elements are bonded more securely to the electrode before use. Those techniques result in discharge lamp life and lumen life increasing to two to three times normal, thereby greatly reducing the time, inconvenience, and cost of lamp maintenance.

In line with the foregoing, a discharge lamp system constructed according to the invention includes a discharge lamp and means operatively coupled to the discharge lamp for supplying a lamp arc current to the discharge lamp that has a reduced crest factor. In addition to other benefits, that results in a reduced product of the in-phase voltage and current dissipated in the lamp system. According to one aspect of the invention, the means operatively coupled to the discharge lamp includes a ballast configured to supply a lamp arc current to the discharge lamp so that the lamp arc current has a waveform that is substantially a squarewave. According to another aspect, the means operatively coupled to the discharge lamp includes a ballast configured to supply lamp arc current to the discharge lamp so that the lamp arc current has a crest factor of a predetermined value (a conventional ANSI value) and waveform conditioning means operatively coupled to the ballast for causing the lamp arc current to have a crest factor less than the predetermined value.

The waveform conditioning means may include a module configured to be retrofitted to an existing ballast, and the module may employ components that combine with the ballast and discharge lamp to form a tuned circuit that results in a reduced crest factor. In addition, the module may be adapted for use with the ballast in a particular one of various types of systems, such as a rapid-start type of discharge lamp system, an instant-start type of discharge lamp system, a pre-heat type of discharge lamp system, and/or a high intensity discharge lamp system.

The above mentioned and other objects and features of this invention and the manner of attaining them will become apparent, and the invention itself will be best understood, by reference to the following description taken in conjunction with the accompanying illustrative drawings.

FIGURE 1 of the drawings is a diagrammatic representation of a rapid-start type of discharge lamp system constructed according to the invention;

FIGURE 2 is a schematic circuit diagram of the waveform conditioning circuitry employed in the rapid-start module;

FIGURE 3 is a diagrammatic representation of an instant-start type of discharge lamp system constructed according to the invention;

FIGURE 4 is a schematic circuit diagram of the waveform conditioning module used in the instant-start type of discharge lamp system;

FIGURE 5 is a diagrammatic representation of a pre-heat type of discharge lamp system constructed according to the invention;

FIGURE 6 is a schematic circuit diagram of the waveform conditioning module used in the pre-heat type of discharge lamp system;

FIGURE 7 is a diagrammatic representation of a discharge lamp system constructed according to the invention that includes a squarewave producing ballast; and

FIGURE 8 is a diagrammatic representation of a discharge lamp electrode burn in circuit.

Referring now to Fig. 1, there is shown a discharge lamp system 10 constructed according to the invention. Generally, the system 10 includes one or more discharge lamps (such as the lamps 11 and 12) and means operatively coupled to the discharge lamps for supplying a lamp arc current to the discharge lamps that has a reduced crest factor. In other words, the system 10 includes means for slowing electrode deterioration by powering the discharge lamps so that a lamp arc current having a reduced crest factor results.

The crest factor can be reduced in several ways as subsequently described. But, first consider the lamps 11 and 12 and the general manner in which they are supported and powered. Although any of various types of discharge lamps may be employed, the lamps 11 and 12 are conventional fluorescent lamps. The lamp 11 has two-terminal electrodes 13 and 14. Similarly, the lamp 12 has two-terminal electrodes 15 and 16, and the lamps 11 and 12 are plugged into a convention fluorescent lamp fixture 17 so the electrodes are connected to a conventional ballast 18 within the fixture 17.

Crest factor reduction is accomplished in the system 10 by retrofitting the lamps 11 and 12 and the ballast 18 with a waveform conditioning module 20. The module 20 includes circuitry mounted in a suitable manner, such as on a circuit board that is encapsulated or otherwise suitably housed, for example. The module 20 is placed in the fixture 17 where it is wired into the existing fixture circuitry as subsequently described to produce the system 10.

Before modification, the fixture 17 is wired to enable first and second input lines 21 and 22 to connect the ballast 18 in a known manner to an external source of any alternating current, such as 110-VAC source

(not shown), via input terminals A and B. In addition, output lines 23 and 24 connect the ballast 18 to the electrode 13 of the lamp 11, output lines 25 and 26 connect the ballast 18 to the electrode 15 of the lamp 12, and output lines 27 and 28 connect the ballast 18 to the electrodes 14 and 16 of the lamps 11 and 12, all in a known way.

The module 20 is retrofitted to the fixture 17 by breaking either one of the first and second input lines 21 and 22 and connecting terminals 31 and 32 of the module 20 at the break in the line, Fig. 1 showing a break in the input line 21 for that purpose. In addition, the output lines 23 and 24 are broken where indicated and the terminals 33-36 of the module 20 are connected at those breaks, Fig. 1 utilizing "x..x" to illustrate each break. Once the module 20 has been connected in that manner, the system 10 operates with a reduced crest factor that substantially lengthens the life and lumen life of the discharge lamps 11 and 12.

Of course, the precise manner in which the module is connected to an existing discharge lamp system depends on the waveform conditioning circuitry employed in the module. In that regard, any of various circuits designed according to known techniques using known components may be used within the broader inventive concepts disclosed as long as the circuit operates in conjunction with the existing discharge lamp and ballast to reduce the lamp arc current crest factor. Examples of circuitry employed in modules suitable for use with rapid-start type, pre-heat type, and instant-start type discharge lamps are described subsequently.

Considering now Fig. 2, there is shown a schematic circuit diagram of the circuitry employed in the module 20 that operates with the ballast 18 and the lamps 11 and 12 in the rapid-start type discharge lamp system 10. Generally, the module 20 includes a tuned gyrator circuit having an inductor L_1 and fuse F_1 connected in series across the terminals 31 and 32. The inductor L_1 is mutually coupled to another inductor L_2, both the inductors L_1 and L_2 being any of various known inductive devices including ones synthesized artificially by transformation or other means. Typically L_1, by itself, improves the lamp arc current crest factor of most systems and therefore, is critical to any such circuit, and the values of L_1 and L_2 are chosen according to known circuit design techniques to operate with a semi-conductor switch, a diode, or a transistor Q_1 and a capacitor C_1 in a circuit that includes transistors Q2-Q9 diodes D_1-D_4, resistors R_1 and R_2, and current regulators Rg1-Rg4 as subsequently described.

Operating power is supplied to the circuit by means of a diode bridge that includes diodes D_5 and D_6, filter capacitor C_2 and discharge resistor R_3. Voltage is supplied to that diode bridge by means of the inductor L_2 which is inductively coupled to the inductor L_1.

Level shifting within the gyrator network is achieved by use of a diode across capacitor C_1 or triggering transistor Q_1 (or any other type of switch) off and into full saturation in a time sequence and a duty cycle such that the time rate of change of current through the inductor L_1 and the time rate of change of voltage across the capacitor C_1 are harmonically related and also synchronized. Among other benefits, level shifting across capacitor C_1 is a method of reducing the electrical burden and extending the useful life of any capacitor in such a circuit by not requiring the capacitor to charge and discharge each half cycle. Regarding Q_1, it can be replaced along with its drive circuitry, within the broader inventive concepts disclosed, with a diode to produce level shifiting with no variable control as is afforded with Q1 and its associated circuitry.

Proper timing to obtain the saturation and fully open limits of Q_1 are accomplished by the other components. Transistors Q_5 and Q_6 form a differential amplifier pair, driven respectively by transistors Q_4 and Q_7. Between terminals 35 and 34 there appears an alternating current voltage sinusoidal waveform of approximately five volts peak. The base of the transistor Q_7 is referenced to the voltage on the terminal 35 and the base of the transistor Q_4 is clamped to the zero voltage reference level of the terminal 34. The diodes D_5 and D_6, the capacitor C_2, and the bleeder resistor R_3 convert the sinusoidal voltage which exists across the terminals 34 and 35 into a direct current potential of approximately five volts at the node where the diode D_5 and D_6 are connected together (referenced to the terminal 34).

When the voltage potential of the terminal 35 rises passing through zero referenced to the terminal 34, the transistor output pair Q_8 and Q_9 of the differential amplifier become offset. Then, the driver transistor Q_3 is triggered on into full saturation, thus clamping the base of the output load transistor Q_2 to zero potential and turning it off. At that time, the direct current potential at the node where the resistor R_2 and the diode D_1 are connected together rises to approximately $R_1/(R_1 + R_2) \times V_{36}$ (where V_{36} is the voltage referenced to terminal 34), thus providing sufficient bias current to turn the transistor Q_1 on into full saturation. When the potential of the terminal 35 again traverses through to its peak and back to zero, as it passes through zero, the differential comparing process reverses and the transistor Q_1 becomes open, and remains open until the voltage at the terminal 35 again passes through zero and proceeds to go positive with respect to the terminal 35.

Within the framework of the discharge lamp system 10, the sinusoidal potential across the terminals 34 and 35 provides continuous and appropriate heater voltage to the electrode 13 of the lamp 11 and, by

means of the diodes D_5 and D_6, the capacitor C_2, and the resistor R_3, operating voltage for the level-shifter circuit comprising the transistors Q_1-Q_9. The light emitting diode D_7 is connected in series with the resistor R_5 across the terminals 34 and 35 to provide an indication when power is on and the circuit is operational. If the circuit fails, such as by the fuse F_1 blowing or the primary or secondary of the transformer T_1 shorting or opening, the diode D_7 goes out to facilitate troubleshooting.

Also within the framework of the discharge lamp system 10, the capacitor C_1 is a constituent part of the current waveform conditioning path to the discharge lamp 11. The net impedance counterpoising the effective negative resistance of the discharge lamp is a positive value of the type A ± jB, wherein the reactance of the inductor L_1 is transformed as a complex conjugate across the discharge ballast transformer T_1 in the form

$$Z = Z_{11} + \left| \frac{\omega M}{Z_{22}} \right|^2 [R_L - j(\omega L_2 + X_{C1})]$$

Z is the impedance at the input to the overall discharge lamp network (across the input terminals A and B). Z_{11} is the impedance of the inductor L_1, including its internal resistance, and the primary winding of the ballast transformer T_1. The Greek letter omega (ω) is the radian frequency of the network. M is the mutual inductance of the discharge ballast transformer T_1. $M = kL_pL_s$, where k is the coupling coefficient. Z_{22} is the impedance of the lamp secondary side of the transformer T_1, including the secondary winding, the lamp impedance R_L, and the reactance of the capacitor C_1. The form of Z_{22} is $R_L + j(\omega L_s + X_{C1})$. Thus, the impedance from the perspective of either side of the discharge ballast transformer T_1 is the complex conjugate of the other side, transformed by the level

$$\left| \frac{\omega M}{Z_{22}} \right|^2$$

Therefore, the overall current-waveform conditioning path to the discharge lamp includes a gyrator network providing not only the desired predetermined positive resistance but also an appropriate reactance to properly tune for maximum efficiency the transfer of energy at the fundamental frequency to the discharge lamp, and also provide the optimum voltage and current waveforms at the lamp for best longevity.

With the incorporation of the interactive gyrator network, the discharge lamp life and lumen life is extended beyond what it would be if the discharge lamp were connected only to a ballast. This life extension is achieved by lamp arc current crest factor reduction brought about by precise tuning of the reactances in the gyrator, creating lamp arc current waveform conditioning such that the waveform has no sharp peak excursions which would cause electrode barium depletion and loss of other emissive coating. The gyrator network overall reacts to the current surge that would normally be associated with the highly inductive ballast transformer when the lamp fires on each half cycle of the alternating current.

Life extension is also accomplished by an improved starting cycle (for rapid start systems) that is achieved by providing through the gyrator network a controlled increase in electrode heater voltage during the starting process. Proper heating of the cathode is achieved before the ignition of the arc, thereby extending electrode life.

In addition, improved lumen life results from reduced watt-loading brought about again by controlling the voltage and arc current waveforms of the lamp to reduce sharp excursions that can result in non-elastic collisions at the phosphor surface (i.e., reduce the crest factor or ratio of the peak value to the rms value). Also, reduced beat frequency flicker is brought about by precise tuning of the reactive components to ensure symmetry of the light output waveform.

Moreover, system efficacy improves by improving the lamp power factor. Again, system tuning corrects any inherent lamp voltage arc current out-of-phase condition by the transformed impedance through the gyrator network. Efficacy is also increased as RFI/EMI is reduced by waveform filtering. Also by waveform filtering, voltage transient and surge protection for the lamp is obtained.

Considering now Figs. 3 and 4, there is shown another discharge lamp system 100 constructed according to the invention, along with circuit details of a module 120 used in the system 100. The system 100 is similar in many respects to the system 10 so that only differences are described in further detail. For

convenience, reference numerals designating parts of the system 100 are increased by one hundred over those designating similar parts of the system 10.

Commonly referred to as an instant-start type of discharge lamp system, the system 100 includes one or more discharge lamps of the known type having one-terminal electrodes, (i.e., a lamp 111 having one-terminal electrodes 113 and 114 and a lamp 112 having one-terminal electrodes 115 and 116). The lamps 111 and 112 are plugged into a known type of fixture 117 where they are powered by a known type of ballast 118 having input lines 121 and 122 for coupling to an external source of alternating current, and output lines 123, 125, 127, and 128 coupled to the lamps 111 and 112.

According to the invention, a module 120 is connected to one of the input lines 121 and 122, and to the output lines 127 and 128 of the ballast 118 by breaking the input lines where indicated by "x...x" and then connecting terminals 131-136 of the module 120 at the breaks as indicated in Fig. 1. That results in a reduced crest factor in a manner similar to that described above for the system 10. The circuitry utilized in the module 120 being quite similar to that employed in the module 20.

Unlike the module 20, the light emitting diode D_7 and resistor R_5 of the module 120 is connected across the inductor L_1. However, that arrangement functions in a similar way to the arrangement employed in the module 20. That is, if the current fails, such that the fuse F_1 opens, the diode D_7 also will go out which will facilitate troubleshooting. In addition, the module 120 includes a capacitor C_3 and a resistor R_6 that are not included in the module 20, they being connected in the output line 128 as part of the tuned gyrator circuit. Because the lamp 112 in the system 100 inherently maintains an impedance characteristic independent from the lamp 111, it is therefore necessary to fine tune the arc current waveform in connection with the tuned gyrator circuit for maximum improvement in the lamp arc current crest factor. That fine tuning is accomplished by the capacitor C_3 and the resistor R_6. Of course, the precise circuitry employed in the module 120 and the precise manner in which it is connected to the ballast 118 can vary within the broader inventive concepts disclosed while still reducing the lamp arc current crest factor for lamp lumen life and lamp life extension purposes.

Considering now Figs. 5 and 6, there is shown yet another discharge lamp system 200 constructed according to the invention, along with circuit details of a module 220 used in the system 200. The system 200 is similar in many respects to the system 10 so that only differences are described in further detail. For convenience, reference numerals designating parts of the system 200 are increased by two hundred over those designating similar parts of the system 10.

Commonly referred to as a pre-heat type of discharge lamp system, the system 200 includes one or more discharge lamps of the known type having two-terminal electrodes, (i.e., a lamp 211 having two-terminal electrodes 213 and 214). The lamp 211 is plugged into a known type of fixture 217 where it is powered by a known type of ballast 118 having input lines 221 and 222 for coupling to an external source of alternating current, and output lines 233, 224, 235, and 228 coupled to the electrodes 213 and 214 of the lamp 111.

Those connections result in a capacitor C_0 in the module 220 being connected across the input lines 221 and 222 and the other circuitry in the module 220 being connected in the output lines as shown in Fig. 6. The circuitry of the module 220 utilizes known circuit design techniques and components to tune the combination of the ballast 218 and lamp 211 in the system 200 in order to improve lamp ignition and reduce the crest factor. Extended lumen life and lamp life results as explained above.

The circuitry includes a diode bridge arrangement of diodes D_8-D_{11} maintaining a D.C. potential but of varying magnitude across lines 233 and 235. As an A.C. potential is applied to the input lines 221 and 222, initially an open circuit potential will result across terminals 213 and 214. concurrently, initially a static D.C. potential will exist across lines 233 and 235. That static-potential causes a current to flow through the resistor bridge R_1 and R_2, charging up the capacitor C_1 at the rate of $I = C(dv/dt)$ to a potential V_1. As the potential V_1 is reached and conditioned in form by the resistor R_3 and the diode D_1, the breakdown potential of the silicon bilateral voltage triggering switch M_1 is exceeded, thus causing it to saturate and thus provide a low impedance path for current to flow into the base of Q_2 and also apply a potential to the gate of Q_3.

With Q_2 activated ON, Q_1 is subsequently turned on, which further enhances the turn on of Q_2. The potential at the gate of FET Q_3 is such that Q_3 is actuated into an ON condition, then appearing in series with Q_2, and hence a low impedance path is generated between lines 233 and 235, limited by the saturation resistance of Q_1, Q_2, Q_3, and diodes D_2, D_3, D_4, and D_5.

At that time, a low potential across and a relatively high current through the terminals 233 and 235 occurs, thus causing a potential $V_2 = L(di/dt)$ to appear across T_2 and the ballast, L consisting of the total inductance of T_2 and ballast 218.

As current passes through the diodes D_3, D_4, and D_5, a potential appears across the resistor R_6, and

therefore across the resistor bridge R_4 and R_5 and the capacitor C_2. As the capacitor C_2 charges up in potential, SCR Q_4 is triggered ON, causing the gate potential of Q_3 to be below its trigger level, turning Q_3 OFF and thus forcing the potential at the base of Q_2 to be below that of its emitter, turning Q_2 and Q_1 OFF.

With Q_1, Q_2, and Q_3 turned OFF, very high D.C. potential V_3 appears across lines 233 and 235 due to the build up at the rate of V_2 = L(di/dt) across T_2 and the ballast. That potential V_2 is sufficient to cause ignition of the lamps 211, thus causing the potential difference between cathodes 213 and 214 to drop to the operating or running potential of the lamp, and also below the breakdown triggering level of the switch M_1. Thus, the potential between lines 233 and 235 remains in the open condition as long as the lamp 211 operates in the run mode. Should lamp 211 not ignite, the above process will be repeated.

Primary winding T_2 is mutually coupled to secondary windings T_{2A} and T_{2B}. The secondary rms voltage output of T_{2A} and T_{2B} is approximately 4-VAC. Diodes D_6 and D_7 are connected in series with T_{2A} and T_{2B} respectively which produce a pulsating D.C. heater rms voltage of 2-VDC to appear across the electrode of lamp 211 in an alternating fashion that is synchronized with the alternating current appearing across the lamp.

When electrode 213 is the cathode for one half cycle, it is heated which makes it more electron emissive. The anode, electrode 214, is not heated because it is not required to "send" any electrons to the other end of the lamp. Conversely, when the electrode 214 is the cathode for the alternate half cycle, it is heated and the anode, electrode 213, is not. Subsequently, diodes D_6 and D_7 create a pulsating cathode heater voltage that only appears when needed and in conjunction with the inductance of T_2 and capacitance of C_0 serve to properly tune the system such that the current waveform, once the lamp is ignited through the action of the Q_1, Q_2, Q_3, D_1, D_2, D_3, D_4, and D_5 network, also provides efficient pulse ignition and a low lamp arc current crest factor in lamp 211 which improves lamp lumen life, improves lamp mortality, and reduces lamp watt loading.

Considering now Fig. 7, there is shown still another discharge lamp system 300 constructed according to the invention. The system 300 is similar in some respects to the system 10 so that only differences are described in further detail. For convenience, reference numerals designating parts of the system 300 are increased by three hundred over those designating similar parts of the system 10.

Unlike the system 10, the system 300 does not include a module that has been retrofitted to an existing ballast. Instead, it includes a ballast 318 that utilizes known circuit design techniques and components to produce a lamp arc current having a squarewave-type waveform. Thus, the crest factor is well below 1.7, approaching unity. In that regard, the term "squarewave-type" means that the waveform looks something like a squarewave even though it may be somewhat rounded or sloped, and that results in a crest factor that is substantially less than 1.7.

Thus, the invention extends discharge lamp life by slowing electrode deterioration by producing a reduced crest factor that is less than that of existing systems (i.e., less than about 1.7), either with a waveform conditioning module that is retrofitted to an existing ballast or with a ballast that produces a squarewave-type waveform. Discharge lamp life increases to two to three times normal and the time, inconvenience, and cost of lamp maintenance decreases appreciably.

Concerning deterioration of the emissive coating on the electrodes, that is slowed as mentioned above by preheating the electrode before, during, or after fabrication so that the emissive elements are bonded more securely to the electrode before use. That may be done in the case of filament-type electrodes (filaments) by supplying power to the filaments for a period of time with no arc current flowing (i.e., before use), preferably at any voltage that specifically causes the electron emissive material on the lamp electrode to bond more readily to the filaments or electrodes. Fig. 8 is a diagrammatic representation of a discharge lamp electrode burn-in circuit.

The barium, rare earth oxides, and other elements that are typically packed onto the fluorescent lamp electrodes in a powdery form are susceptible to being "blown off" or eroded by lamp ignition and the lamp arc current, particularly during initial use of the lamp. The electrode "burn-in" method fuses the powdery elements to the electrode, making them less susceptible to being eroded by the starting cycle or the lamp arc current and subsequently, improve lamp lumen life and lamp mortality.

Although exemplary embodiments of the invention have been shown and described, many changes, modifications, and substitutions may be made by one having ordinary skill in the art without necessarily departing from the spirit and scope of the invention. For example, one could combine conventional ballast circuitry and waveform conditioning means in what might be called a tuned ballast (instead of having waveform conditioning means added to an existing ballast), and such an arrangement is intended to fall within the scope of the claims.

Claims

1. A discharge lamp system comprising:
a discharge lamp;
a ballast coupled to the discharge lamp for supplying lamp arc current having a predetermined crest factor to the discharge lamp; and
a waveform conditioning module coupled to the ballast for causing the lamp arc current to have a crest factor less than the predetermined value.

2. A system as described in claim 1 wherein the waveform conditioning module includes an inductor coupled to the ballast for improving the crest factor to less than said predetermined value.

3. A system as described in claim 2 wherein the inductor is coupled to the ballast between the ballast and a source of electrical power for the ballast.

4. A system as described in claims 1, 2 or 3 wherein the waveform conditioning module includes a capacitor coupled to the ballast and the lamp between the ballast and the lamp.

5. A system as described in claim 4 wherein the waveform conditioning module includes a switch coupled across the capacitor and circuit means for operating said switch so that the time rate of change of current through the inductor and the time rate of change of voltage across the capacitor are harmonically related and synchronized.

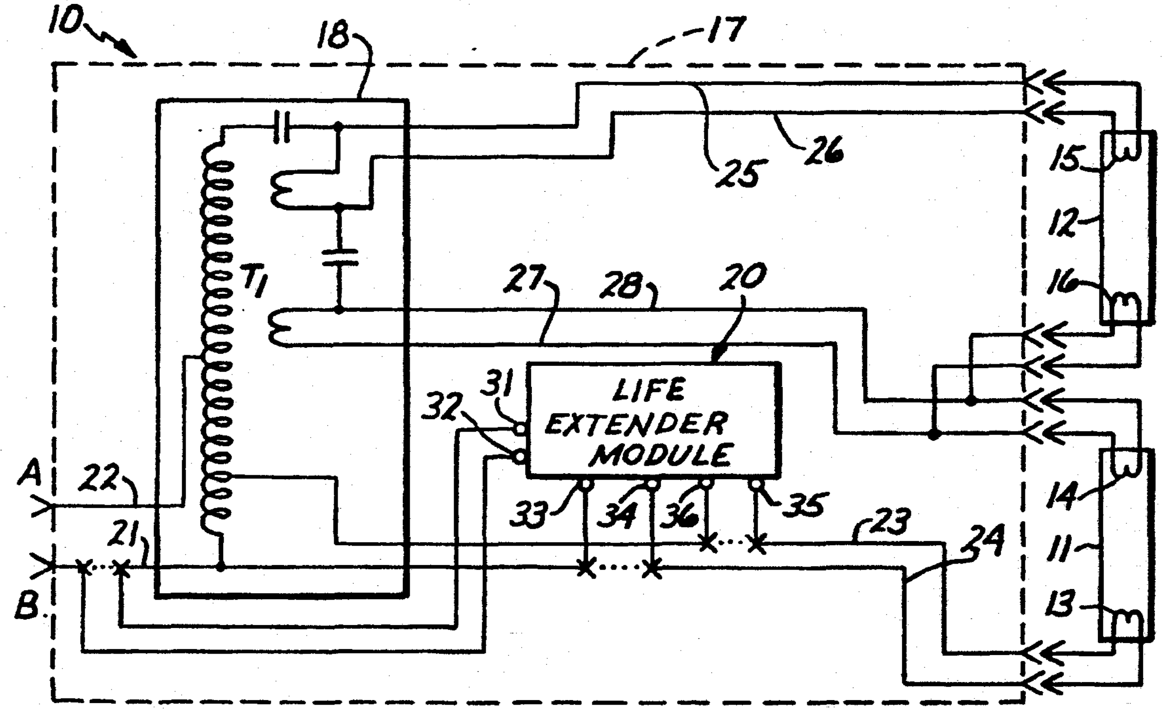
6. A system as described in claims 1, 2, 3, 4 or 5 wherein the ballast has a primary coil and the waveform conditioning module includes a tuned gyrator network coupled to the primary coil of the ballast.

7. A system as described in claims 1, 2, 3, or 5 wherein the discharge lamp has first and second electrodes which alternately function as an anode and a cathode and the waveform conditioning module includes circuit means for heating each of the first and second electrodes when such electrode is serving as a cathode.

8. A method of extending the life of a discharge lamp wherein the lamp is coupled to a ballast which supplies the lamp with lamp arc current having a crest factor of a predetermined value, said method comprising:
retrofitting the lamp and ballast with a waveform conditioning module by coupling the waveform conditioning module to the ballast to cause the lamp arc current to have a crest factor less than the predetermined value.

9. A method of extending discharge lamp life comprising:
slowing deterioration of an emissive coating on a discharge lamp electrode.

10. A method as described in claim 9 wherein the step of slowing includes preheating the electrode in the absence of lamp arc current utilizing heat or power before, during, or after fabrication in order to bond the emissive coating on the electrode.


10
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T1
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LIFE EXTENDER MODULE
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13

FIG. 1

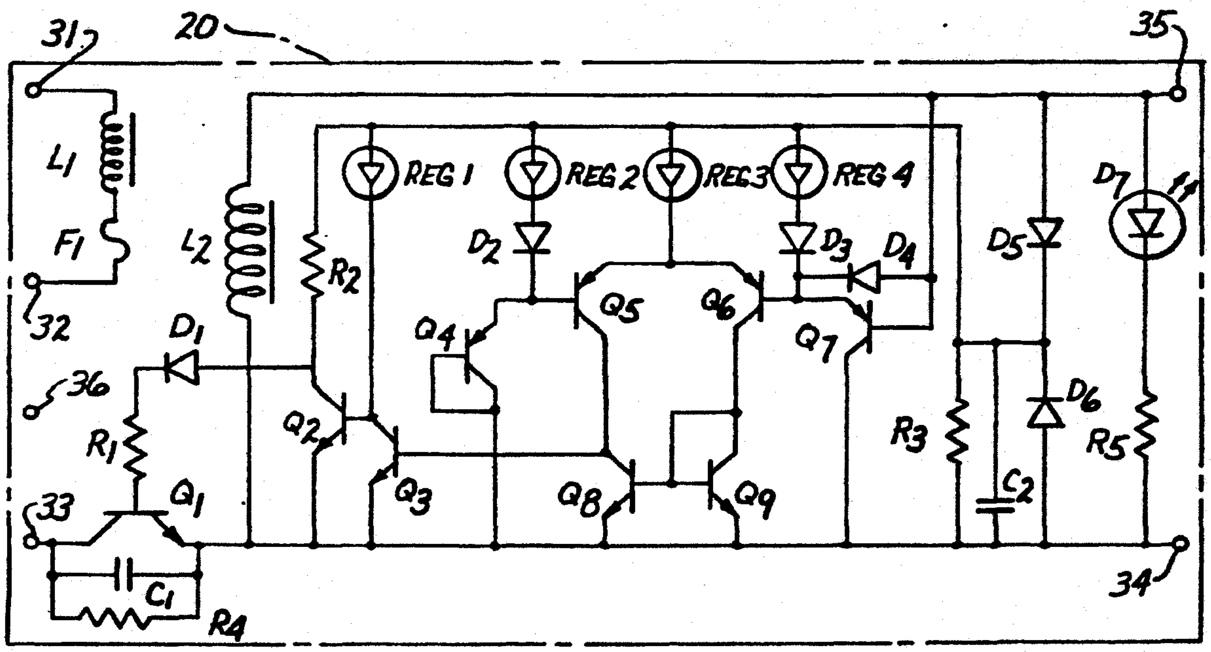
31
20
35
L1
L2
F1
32
D1
36
R1
Q1
33
C1
R4
R2
REG 1
REG 2
REG 3
REG 4
D2
D3
D4
D5
D7
Q4
Q5
Q6
Q7
Q2
Q3
Q8
Q9
R3
C2
D6
R5
34

FIG. 2

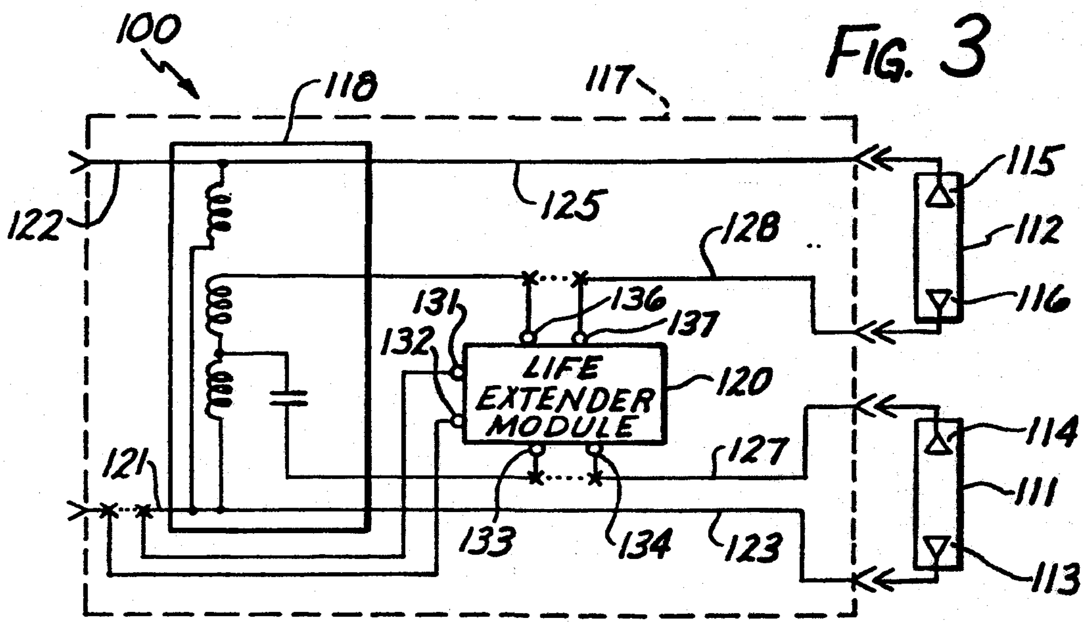
100
118
117
122
125
115
112
128
116
131
136
137
132
LIFE EXTENDER MODULE
120
114
121
127
111
133
134
123
113

FIG. 3

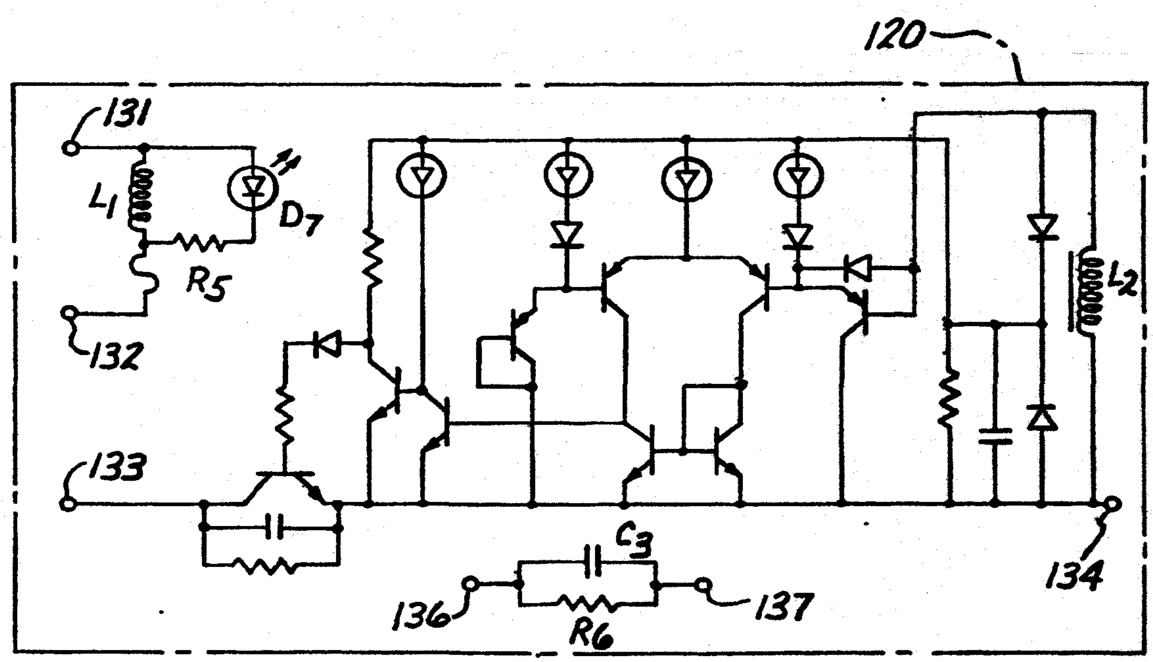
120
131
L1
D7
R5
132
L2
133
C3
134
136
R6
137

FIG. 4

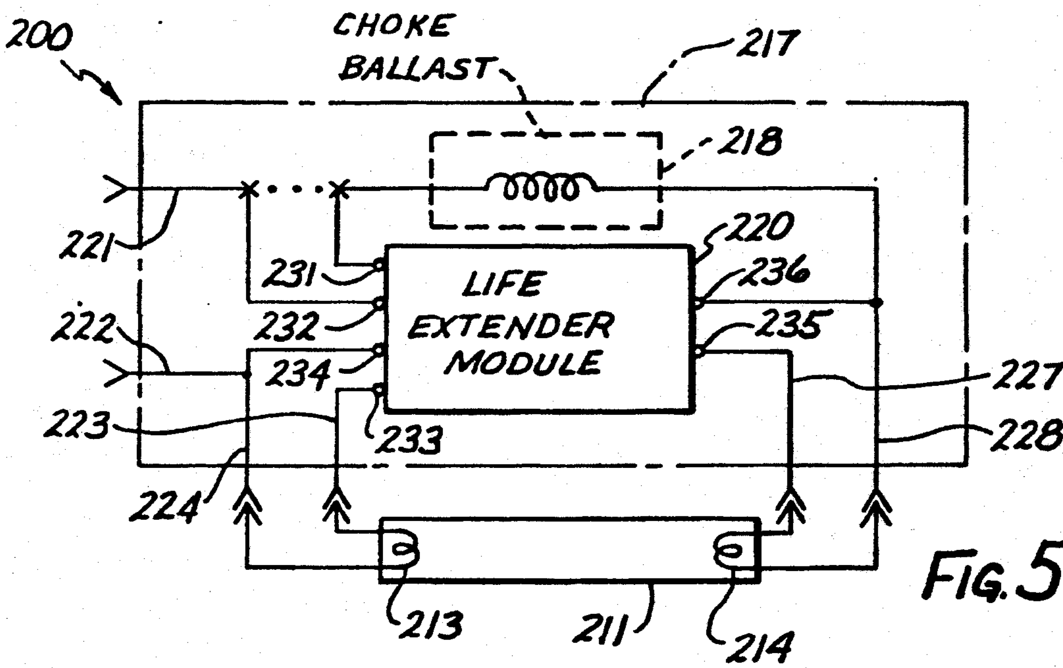
200
CHOKE
BALLAST
217
218
220
221
231
232
236
LIFE
EXTENDER
MODULE
222
234
235
227
223
233
228
224
213
211
214

FIG. 5

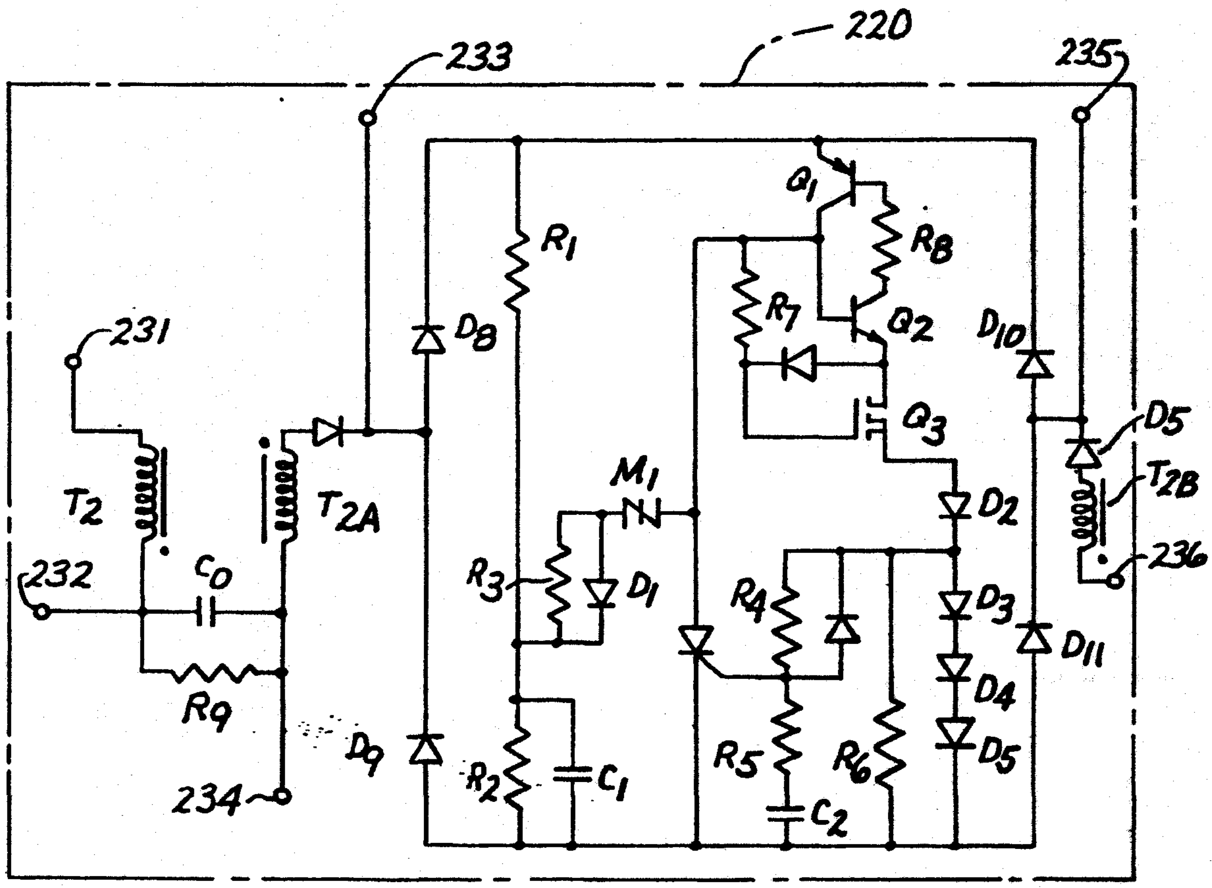
220
233
235
Q1
R8
R1
R7
Q2
231
D8
D10
Q3
D5
M1
T2
T2A
D2
T2B
236
232
C0
R3
D1
R4
D3
D11
Rq
D4
D9
R5
R6
D5
R2
C1
234
C2

FIG. 6

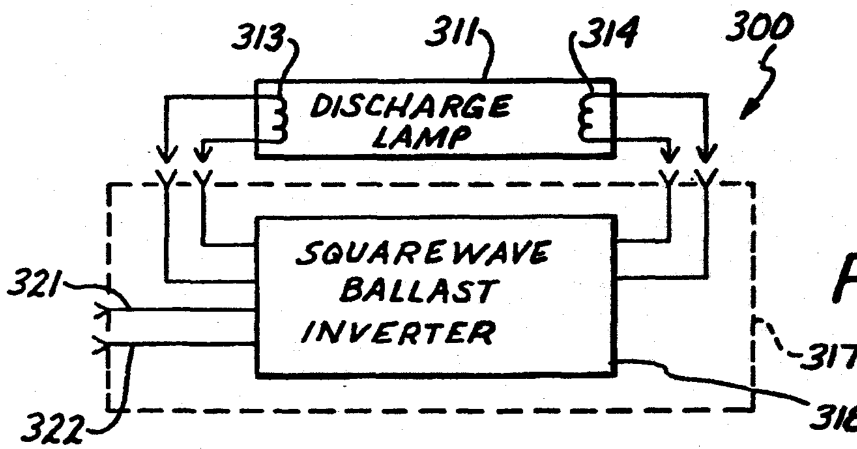
313
311
314
300
DISCHARGE LAMP
SQUAREWAVE BALLAST INVERTER
321
322
317
318

FIG. 7

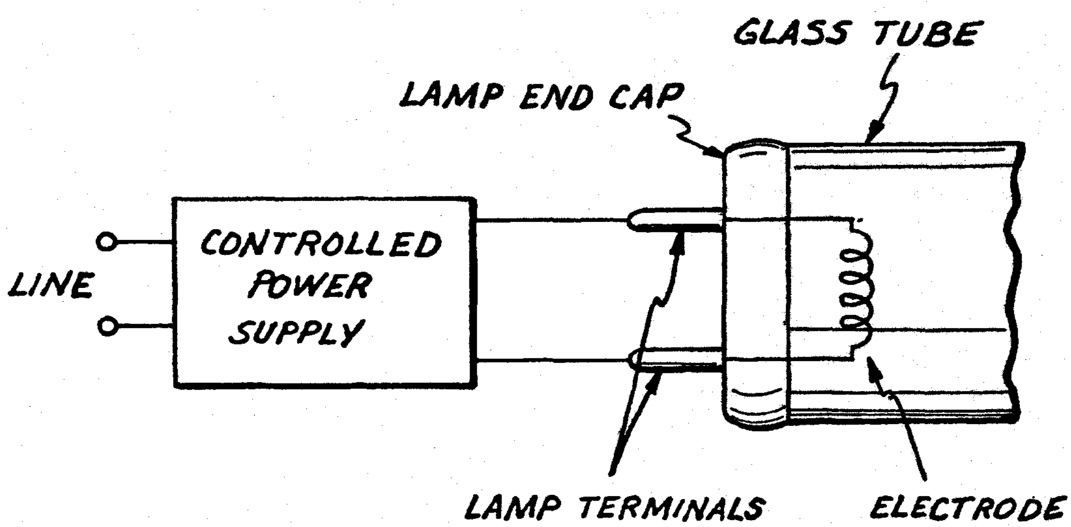
GLASS TUBE
LAMP END CAP
LINE
CONTROLLED POWER SUPPLY
LAMP TERMINALS
ELECTRODE

FIG. 8